SURGERY OF TRAPEZIOMETACARPAL JOINT ARTHRITIS: INCREASING OR DECREASING THE DEGREES OF FREEDOM?

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INTRODUCTION

The intact TMC joint has 2 DoFs in flexion-extension (F-E) and abduction-adduction (A-A). Because the F-E and A-A axes are not perpendicular or concurrent with each other an automatic pronation-supination (P-S) also naturally occurs [1, 2]. This unique anatomical configuration allows both dexterous motion and forceful grip force, but it also leads to a high prevalence of joint degenerative osteoarthritis [3]. Currently, several surgical methods are available for the treatment, but they affect the natural biomechanics of the joint. After a joint fusion, the joint is frozen and all joint DoFs disappear. Therefore, monoarticular muscles acting at the TMC joint become useless and polyarticular muscles are not obligated to equilibrate the fused joint. When a ball-and-socket arthroplasty is performed the restricted P-S becomes free and the corresponding component of the joint moment which was previously equilibrated by joint boundaries and ligaments has to be equilibrated by muscles. The goal of this study was to examine the influence of freezing or liberating DoFs at the TMC joint on muscle and joint forces reorganization.

METHOD

The computer simulation developed in this study was adapted from the original normative model [4]. Because the kinematic model of [4] considered the TMC joint articulated around 2 orthogonal and crossing rotation axes we incorporated the anthropometric data of axes locations/orientation reported by [1] to account for the automatic P-S motion and model a more anatomically accurate joint (Fig. 1, left). Coordinate system transformations were conducted using the transformation matrix [T] such that \(O_5' = [T] \times O_5\) and \(O_6' = [T] \times O_6\) with:

\[
T = \begin{bmatrix}
c_{Fa} & s_{Fa} & -sA & t_x \\
c_{Fa}sR - s_{Fa}cR & s_{Fa}sR + c_{Fa}cR & c_{Aa}R & t_y \\
c_{Fa}cR + s_{Fa}sR & s_{Fa}cR - c_{Fa}sR & c_{Ac}R & t_z \\
0 & 0 & 0 & 1
\end{bmatrix}
\]

\(c\) and \(s\) standing for the cosinus and sinus functions respectively. \(F, A, R, \) rotation angles equal to 6.4, 0, 11.7 degrees and -14.7, 13.6, 0 degrees, for coordinate systems \(O_5'\) and \(O_6'\) respectively. \(t_x, t_y, t_z\) correspond to the translation coordinates and equal to -6.27, 0, 0 mm and 0, 0, 0 mm for \(O_5'\) and \(O_6'\) respectively. Rigid body static laws were applied and joint moments were equilibrated by the 9 muscle forces (FPL, flexor pollicis longus, FPB, flexor pollicis brevis, OPP, opponent pollicis APB, abductor pollicis brevis, APL, abductor pollicis longus, ADPo, adductor pollicis oblique head ADPt, adductor pollicis tranverse head EPL, extensor pollicis longus EPB, extensor pollicis brevis).

Figure 1. Left: Thumb metacarpal and trapezium bone coordinate systems (notations adapted from [1]). Right: Orientations of the simulated thumb tip force.

The thumb assumed a pulp pinch posture [5] and external force was simulated as a unit force vector applied at 75% of the total length of the distal phalanx along 8 directions in the transverse plane (Fig 1, right). Simulated joint angles and thumb tip force were used as input data for the calculation of external joint moments and muscle/joint forces. The underdeterminate problem associated with muscle redundancy was solved with a static non-linear optimization [5].
RESULTS AND DISCUSSION

OPP and APL muscle forces acting on the TMC joint only were thus appropriately set to 0 N by the simulation for the 0 DoF condition. The 0 DoF condition exhibited an overall decrease of 0.8 N in muscle forces in comparison with the 2 DoFs (intact) condition (average among all 9 muscles and 8 force directions). The 3 DoFs condition resulted in a 9.0 N increase of muscle forces with disparate results: FPL was the less influenced (+2.7N) and APL the most (29.0N) (Fig. 2).

**Figure 2.** Thumb muscle force (N) envelope to equilibrate a 1 N external force exerted at the thumb tip in 8 different orientations.

Comparing to the intact joint, IP, MP and TMC joint forces were generally smaller when TMC is fused (Fig. 3).

**Figure 3.** Joint forces in the 0, 2, and 3 DoFs conditions. For each condition, the first, second and third columns represent the IP, MP and TMC joints respectively. Normal (black) and shear (grey) force components are shown.

However, IP and MP joint forces were also occasionally greater (e.g. +25.3 and 42.8% respectively in PALMAR-LATERAL direction). On the contrary, excessively large joint forces were observed in the 3 DoFs condition, especially at the TMC joint (88.3 vs. 7.2 N, average across all external force orientations).

CONCLUSION

This study gains new insights into the biomechanical consequences of two TMC joint osteoarthritis surgeries. Overall, the ball-and-socket arthroplasty condition lead to larger muscle/joint forces but we also pointed out some interesting particularities in the fusion condition such as a potential overuse in the small FPB muscle as well as occasionally greater forces at IP and MP joints.

REFERENCES